CUYAHOGA VALLEY NATIONAL PARK
2001 DEER EXCLOSURE REPORT

Covering the period from summer 1999 through summer 2001

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SUMMARY

The Deer Exclosure Study reveals several impacts of white-tailed deer on the vegetation of Cuyahoga Valley National Park. Major findings are that deer are severely impeding the growth of seedlings in bottomland forests, suppressing the increase of groundcover native diversity in upland forests, and decreasing the amount of foliage in the forests and fields, while in upland fields, deer may be enhancing the diversity and density of groundcover. Additionally, negative change in height of the tallest seedlings is identified as an indicator of high deer impact areas.

Recommendations are that results of this study be integrated into the analysis of Long Term Ecological Monitoring data to identify the areas of the park with the most severe deer impacts and the attributes of such areas, that the relationship of deer and the spread of garlic mustard be investigated, that the exclosure study continue on a three to five year cycle of remeasurement, and that means of preventing and ameliorating excessive negative impacts of deer on CVNP's vegetation be investigated.

INTRODUCTION

Trends in white-tailed deer population growth and increases in observed deer damage to vegetation have led to an increased interest in the impact of the deer on vegetation at Cuyahoga Valley National Park (CVNP). In 1998 an extensive park-wide Long Term Ecological Monitoring System (LTEMS) was initiated to monitor changes in vegetation. During the initial year of that study, variation in environmental conditions (soil types, aspect, slope, past history of disturbance, etc.) among sites complicated the analysis of the data with regard to isolating the influences of deer on the park's vegetation. This difficulty led to the conclusion that a system of fenced deer exclosures with paired unfenced plots would enhance analysis of the influence of deer on vegetation versus other environmental factors (USDI 1999). In the winter of 1999, twelve exclosures were constructed and baseline measurements of all variables (see below) were taken during the spring and summer of that year. In 2001, all variables, with the exception of overstory tree variables, were measured for a second time. This report analyzes the results of the 2001 measurements. In 1998, deer densities in CVNP were between 45 and 90 deer per square mile. (Underwood and Coffey 1999). Preliminary analysis of 2001 deer population monitoring data indicates that the population has not changed greatly during the period of exclosure.

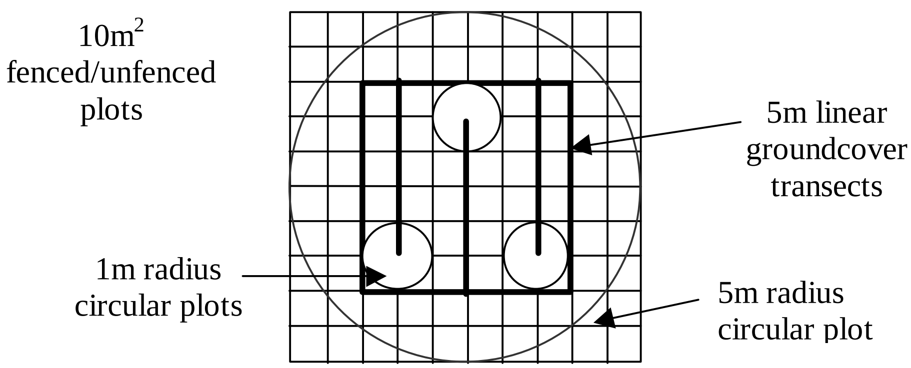
The sites were carefully selected for consistency of site conditions between the fenced (treatment) and unfenced (control) plots for each pair. Each unfenced plot is situated adjacent to its fenced plot in the same forest cover type, on similar soil, on the same contour, slope and aspect. The only appreciable difference in physical conditions between the fenced and unfenced plots is the exclusion of deer from the fenced plots. This single variable is the primary difference between the plots. Except in three variables in which significant differences existed at the initial reading in 1999 (see Appendix A pages A-3 and A-4 for a summary of baseline measurements), differences in vegetative variables between the fenced and unfenced plots can reliably be attributed to the effects of white-tailed deer on the control plots. For those variables which did display significant differences in 1999, any significant difference in that variable in the same stratum in 2001 has been assumed to be a byproduct of pre-existing conditions, rather than an effect of treatment.

METHODOLOGY

The methodology follows the protocol described in USDI 1999 for monitoring the effects of white-tailed deer on park vegetation. The fenced plots are ten meters square, with an unfenced control plot located within approximately ten meters of the fenced treatment plot. The unfenced plots were not placed directly adjacent to fenced plots, so as to reduce the possibility of a "fenceline effect" in which control plots can be heavily browsed due to the presence of the exclosure fence (Russell et. al. 2001). In order to cause as little disturbance to vegetation as possible during construction of exclosures, (in both the treatment and control plots) construction took place during the dormant months late in the winter of 1999. The fencing was installed to a height of eight feet, with mesh greater than four inches to allow small herbivores continued access to the sites. Observed herbivory on two fenced plots during the course of the 2001 fieldwork supports the assumption of continued use of the fenced plots by herbivores other than deer.

The twelve fenced /unfenced paired plots are situated as follows: three upland forest sites, three bottomland forest sites, three upland field sites, three bottomland field sites. This stratification based on landscape position and land cover is consistent with the current LTEMS vegetation monitoring system, and reflects the major physiographic and plant community conditions at CVNP (USDI 1998).

A 2-meter buffer was established around the interior of the fenced plots contiguous with the fence. Three 1-meter radius circular subplots, a 5-meter radius circular subplot, and three 5-meter linear transects were established within the remaining 6-meter x 6-meter area of the treatment plot. The same subplot/transect arrangement was established in the unfenced control plots.



At the center of the 5-meter radius circular sub-plots, overstory species composition of trees greater than or equal to 15 centimeter DBH (using a 10-factor prism), percent canopy cover (using a spherical densiometer following Lemon 1957), percent slope, aspect, percent shrub, grass/sedge, and fern cover, and diameter at breast height and species of all trees greater than or equal to 1.5-meters tall were measured. From the centerpoint of each plot, photographs were taken facing each plot corner. A photo was also taken of the vegetation cover board. The cover board was placed at the mid-point of one randomly chosen 10-meter plot side, and placed so that tree boles would not obscure the board. Coverboard photos were taken from a 13m distance perpendicularly across the plot.

In each of the three 1-meter radius circular sub-plots the following measurements were taken: tree regeneration (seedling tallies by species and size category); height and species of tallest seedling; ocular estimates of percent groundcover composed of rock, wet, trail, herbs (other than grass/sedge and fern); and mean height of herbs.

CVNP has adopted stocking criteria of 67 percent of sub-plots per plot being stocked with 10 or 30 seedlings to sustain low (10) or high (30) deer browse pressure and ensure that the forests regenerate in the event of overstory mortality. The stocking criteria were developed by the U.S. Forest Service to address the high spatial and numerical variability and stochastic nature of forest regeneration. Basically, if a site is considered fully stocked with seedlings, then that site would be expected to adequately regenerate overstory trees in the event of overstory mortality. If a site is not stocked adequately, that site is unlikely to regenerate forest cover in the event of overstory mortality. If an area is under lower deer pressure and meets the stocking criterion for low deer impacts, that area is likely to successfully regenerate. If it does not meet the stocking criteria, it is less likely to regenerate. The same framework applies to the stocking criteria for high deer impacts, except that a greater number of seedlings is required to ensure that enough survive to fill gaps in the canopy created by overstory mortality.

This stocking scheme is based on a weighted count of seedlings in which the shortest class of seedlings is unweighted (seedling classes are defined below), class B is multiplied by 2, class C is multiplied by 15, and class D is multiplied by 30. The sum of these weighted seedling counts is calculated to arrive at the total weighted seedling count for each 1-meter radius sub-plot. The percentage of sub-plots with at least 10 and at least 30 weighted seedlings is derived from this calculation. For a more detailed description of stocking see USDA 1998[c]. The stocking criteria apply only to forested sites, and hence, while reported in the summary results tables in appendix A, they were not analyzed further for fields.

Along each 5-meter linear groundcover transect, the point method was used (pin drop every ten centimeters) to record groundcover hits (after Bonham 1989). Any observed deer browse was recorded at each pin drop, as was the presence of reproductive structures. The data from these transects was used to calculate the Shannon-Weaver diversity index, as well as the native diversity index.

At the center point of the 1-meter radius circular sub-plots and at off-subplot ends of 5m transects, the vertical vegetation profile was measured. Vertical profile was quantified by recording the presence or absence of foliage contacting a 3-meter tall pole graduated into half-meter height intervals. Any foliage (leaves or petioles) contacting the pole in a given height range, regardless of the amount of foliage touching the pole, was counted as a "hit" in that range. These counts were done at six points per plot, for a maximum of 6 hits per plot per height class. For simplicity, the height classes will be referred to as A through E, with A being ground level to one half meter, and E being greater than 2.0 meters.

Groundcover variables on forested sites were measured in May in order to detect spring ephemerals. Tree regeneration variables, vertical vegetation profiles, photos, and spherical densiometer readings were recorded in June and July on forested sites. All measurements at field sites were done in August. During sampling, care was taken to avoid trampling vegetation.

No overstory tree measurements were done during 2001. In the design of the LTEMS, it was recommended that the tree measurements be done only every three cycles (nine years) or in the event of major overstory changes (USDA 1998[a]). Although there was some overstory mortality in the vicinity of the plots in 2001, minor changes in overstory due to mortality were not severe enough to necessitate remeasurement of the overstory variables at that time.

Paired t-tests were used to compare fenced plots to unfenced plots using Sigmastat Statistical Software, version 2.0. Three classes of characteristics were analyzed: groundcover, tree regeneration, and vertical structure. In each of these classes, a number of variables likely to be influenced by deer were compared, as recommended by Stout (USDA 1999).

Groundcover variables were: browse hits; organic litter hits; reproductive hits; total plant hits; Shannon-Weaver diversity (-? (p_i log p_i) where p_i= the proportion of individuals of species i); and Native diversity (Shannon-Weaver diversity excluding non-native plants). Tree Regeneration variables recorded were: seedlings/ha and weighted seedlings/ha; seedlings/ha > 5cm and ≤ 30cm (Height Class A); seedlings/ha > 30cm and ≤ 1m (Height Class B); seedlings/ha > 1m and ≤ 1.5m (Height Class C); seedlings/ha > 1.5m and ≤ 2.5cm dbh (Height Class D); stocking to sustain high and low deer impacts (based on weighted seedling counts); height of tallest seedling; and seedlings/ha white ash, black cherry, sugar maple and red maple. Vertical Structure was quantified by foliage hits at the following heights: 0-.5m (Height Level A); .5-1m (Height Level B); 1-1.5m (Height Level C); 1.5-2m (Height Level D); and >2m (Height Level E). Tables of 2001 data for each habitat are included in Appendix A. Baseline data from 1999 is included in Appendix B. All plant names follow Gleason and Cronquist (1991).

RESULTS AND DISCUSSION

The National Park Service's mission is to "promote and regulate the use of the Federal areas known as national parks… by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (16 U.S.C. section 1). This mission of conservation imposes upon the NPS the duty to ensure that park resources do not become impaired. Because of the conservation mission of the NPS, it is appropriate to err on the side of caution when interpreting data pertaining to impacts on park resources (2001 NPS Management Policies section 4.1). For this reason, it is appropriate to set the threshold value for determining statistical significance in such a way as to err in favor of protecting the resources while still maintaining suitable false-change error rates. Setting threshold values for statistical significance based on management mandates is supported by recent publications (e.g. Elzinga et. al 1998) and is reasonable. Hence, in this report, statistical significance is indicated by a critical p-value of less than 0.10. Results of statistical tests, and other information needed to interpret statistical results are found in Appendix A, rather than in the text. In a limited number of cases, the analysis uses numbers derived from other variables. In these cases, that variable is not reported in Appendix A, so the t and p values will be reported in parenthesis in the text.

Statistically significant differences between the fenced and unfenced plots were found in several variables. There were also other large differences between treatments, which may indicate further impacts of deer that may become statistically significant after longer periods of exclosure. Post hoc power analysis confirmed the low power of all comparisons to detect differences between treatments. This low power, combined with the short period of exclosure makes it difficult to achieve statistical significance even for apparent biologically significant results. For these reasons, the following discussion will present significant results as well as discuss statistically non-significant results that suggest additional biologically significant impacts of deer on the vegetation of CVNP.

UPLAND FORESTS

In upland forests, the native diversity of the groundcover layer is significantly higher on fenced plots. While this 29 percent difference illustrates that deer are having some impact on native diversity, when comparing the 1999 native diversity data with the 2001 data, there were increases in native diversity in both fenced and unfenced plots. The fenced plots showed a much greater increase in diversity over the two years of treatment. Although the increases in diversity inside and outside fences may be related to gypsy moth defoliation (see discussion below), both fenced and unfenced plots were defoliated, and so the different rates of change appear to be due to the influence of deer.

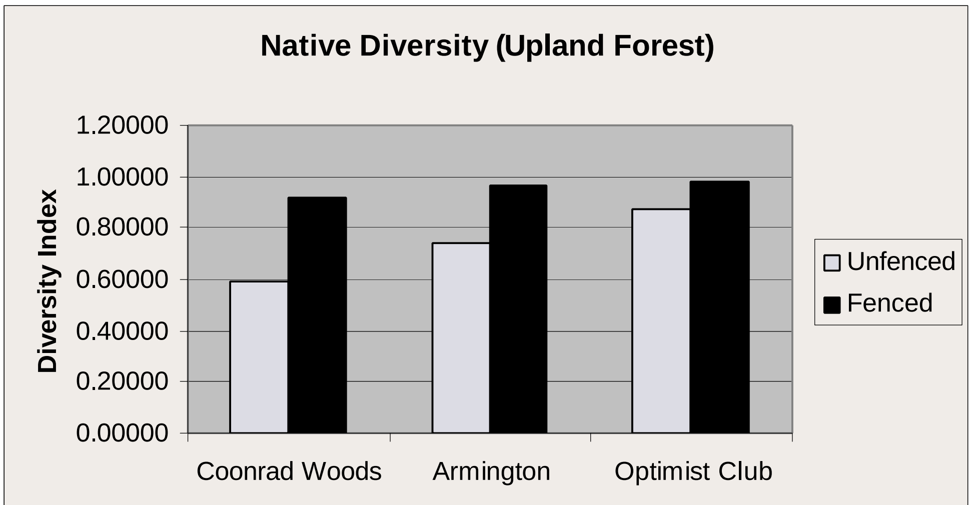


Figure 1

On average, two more species per plot occurred inside the fenced plots. There were no two species that accounted for this difference across the replicates. However it was noted that *Smilacina racemosa*, false solomon's seal, and *Polygonatum pubescens*, solomon's seal, were found only in fenced plots at one replicate, Armington, and not in unfenced plots at any site, while *Alliaria officinalis*, garlic mustard, was not found on fenced plots, but was present on all unfenced plots at one upland forest site, Optimist Club. On the Armington fenced plots, *Smilacina racemosa* was found on one transect in 1999, for a total of two hits. In 2001, the species was found on all fenced transects at the Armington site, for a total of four hits. At this same site, *Polygonatum pubescens* was not found in 1999, but had expanded to 6 hits on one transect in 2001.

During this same time period, *Alliaria officinalis*, which was not found on any upland sites in 1999, expanded to cover 17 percent of the plants recorded on all unfenced transects at the Optimist Club site. This swift expansion, and the lack of a contemporaneous expansion of, or even presence of, an *Alliaria* population in the fenced upland plots presents the possibility that the presence of deer could facilitate the spread of this non-native invasive plant species. It could also be that the differences in *Alliaria* on fenced and unfenced plots are due to the spatial arrangement of the plots in relation to the invasion front of *Alliaria*. Additionally, at Indiana Dunes National Lakeshore some observations indicate that raccoons may facilitate the spread of

Alliaria. (Stumpf, 2002 pers. com.). While raccoons could enter CVNP's exclosures, we do not know whether they do or not.

It is clear that preferred plants such as *Polygonum* and *Smilacina* tend to decrease in abundance under browsing pressure (USDA 1998[d]), while non-preferred plants, such as *Alliaria*, tend to increase due to preferential browsing (Kohlman and Risenhoover 1994). This non-preference is believed to facilitate the spread of non-pref ered invasive plants such as *Alliaria* in areas of moderate to heavy deer browsing (McShea and Rappole 1997).

A recent study in Virginia found that *Polygonatum spp*. and *Smilacina spp*. occurred more frequently inside exclosures than on unfenced plots. That study also showed that these genera had higher reproductive activity when released from browsing pressure (Fletcher et. al. 2001). Other studies have shown that species in the lily family, which includes *Polygonatum* and *Smilacina*, are preferred species for deer, and are sensitive to browsing pressure (See e.g., Augustine and Jordan 1998). This information, coupled with the absence of these species from unfenced plots indicates a possibility that over time, *Polygonatum* and *Smilacina* may experience impacts similar to those of *Trillium grandiflorum* in CVNP (Plona 2002), while Alliaria may increase over time due to the influences of deer. These possibilities should be investigated.

Seedlings per hectare on unfenced plots were nearly double those of fenced plots. This result is not unexpected, as browsing pressure does not always kill seedlings immediately. Rather the pressure of repeated browsing suppresses the height and lateral growth of seedlings (Harmer 1999). This suppression has cumulative effects, since browsing causes seedlings to remain small enough to be browsed by deer for several years longer than if they had not been browsed (Gill 1992). Browsing may stunt the growth of seedlings into the canopy while not greatly reducing seedling numbers (Risenhoover and Maass 1986), unless heavy shade is present, in which case, deer herbivory is more likely to reduce the number of seedlings per hectare through seedling mortality, rather than simply stunting the growth of the seedlings (Canham, et. al. 1994). Since gypsy moth defoliation has increased light levels during the last several years on these plots, it follows that seedling growth would be retarded by deer browse, while total numbers may not be decreased.

This possibility is supported by the fact that while the total number of seedlings was greater in the unfenced plots, this disparity gradually diminishes through taller height classes (for definitions of height classes, see page four). In height class A, the number of seedlings is three times greater in unfenced plots, while in class B, the unfenced plots had only slightly more seedlings per hectare on average. The C height class displays a reversal of the conditions in lower height classes. In this class, as well as in the D height class, the fenced plots have nearly double the seedlings per hectare of the unfenced plots. The fact that the unfenced plots contain many more seedlings than fenced plots, yet the fenced plots contain many more seedlings in taller classes indicates that seedlings protected from deer are much more readily able to progress to taller heights than those under the browsing pressure present at current deer densities within CVNP.

In a deer enclosure study in which known deer densities were maintained in fenced areas, Tilghman found that while seedlings became established at all deer densities, the number of seedlings recruited into greater size classes was strongly influenced by deer density after five years of study (Tilghman 1989). This appears to hold true in the upland forests of CVNP.

The total number of seedlings in upland forests increased in both fenced and unfenced plots from 1999 to 2001. This is likely the result of Gypsy Moth defoliation of the overstory trees, which temporarily increased the light penetration into the understory on several of the plots.

New growth resulting from this defoliation occurred both inside and outside of the fenced plots. Seedling numbers are expected to initially increase, then decrease in the years after defoliation due to canopy closure, competition, and self-thinning (Oliver and Larson 1990). Two replicates had been defoliated in 1999, while one was not. On the two defoliated plots, both the fenced and unfenced plots had similar spherical densiometer readings in 1999 and 2001, indicating similar defoliation and canopy recovery from that defoliation. The undefoliated site (Optimist Club) displayed slight increases in canopy readings over the study period, with a slightly greater increase in canopy cover on the fenced plots.

Due to the defoliation of these two replicates, the variation between replicates within the upland forest habitat was larger than if there had been no defoliation, or if all replicates had been defoliated. This may have resulted in a lower ability to reliably identify deer related differences between fenced and unfenced plots in the upland forests. This confounding effect should diminish over time, allowing for better analysis of the impacts of deer on the vegetation of upland forests.

There was no difference in the average height of the tallest seedling between the fenced and unfenced plots. The average for both fenced and unfenced plots are in the 220 to 230-centimeter range. This height is beyond the convenient reach of deer, and so no difference would be expected.

The species composition of the seedling bank also exhibits large differences between fenced and unfenced plots. The fenced plots contain approximately one-fourth the number of black cherry seedlings per hectare compared to unfenced plots. This could presage a shift in overstory species composition in the event of overstory mortality and replacement from the seedling bank.

Studies in the Allegheny National Forest have shown that high deer densities are correlated with increased black cherry regeneration (Tilghman 1989). Tilghman associated the shift to "near monocultures of black cherry" in the national forest with potential threats of insect or disease epidemics, such as cherry scallop-shell moth, which could become a major cause of overstory mortality if nearly pure black cherry stands were to form. She also outlined adverse impacts to wildlife habitat resulting from this composition shift such as decreases in wildlife food availability and a decrease in available habitat for cavity nesting species (Tilghman 1989). Such detrimental effects could reasonably be expected in the upland forests of CVNP if the number of black cherry seedlings increases disproportionately.

Stocking rates for tree seedlings were generally up from the initial measurements on both fenced and unfenced plots. Fenced and unfenced plots both meet the stocking criteria on average for low deer impacts. However, only the unfenced plots met the criteria for high deer impacts. This incongruous result may be due to the fact that there were many more total seedlings in the unfenced plots, mostly due to greater numbers of seedlings in the smallest size class (see discussion above). Although the stocking assessment scheme takes into account the presence of taller seedlings by weighing them more heavily, if enough smaller seedlings are present, the stocking criteria can be met based on those alone. However, if seedlings are being prevented from progressing to larger sizes, the fact that seedlings are present in the smallest size classes may not be particularly important to overall forest development.

In upland forests, fenced plots exhibited greater vertical structure scores at all height levels except the D level, where it was equal to that on the unfenced plots. However, the vertical profile of the vegetation at the E level displayed a statistically significant difference, with three times as much foliage present on fenced plots compared to unfenced plots. This may indicate that vegetation has more vigor inside the fences due to release from browsing pressure. This also suggests that seedlings from lower levels that grow into this height range exhibit more foliage growth than those on unfenced plots. The overall greater vertical structure in fenced plots supports the conclusion that current deer population levels negatively influence the amount of foliage cover available in upland forested habitats in CVNP.

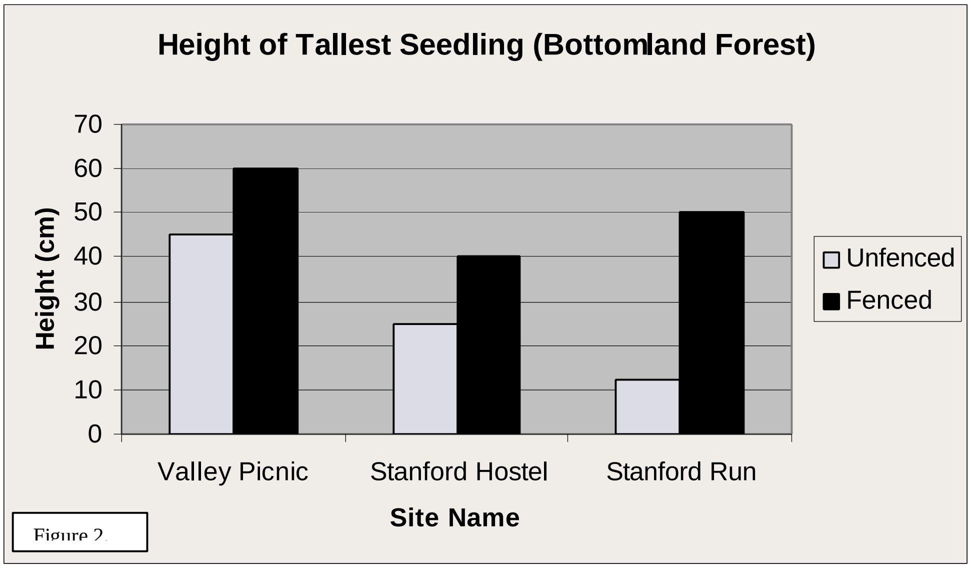
BOTTOMLAND FORESTS

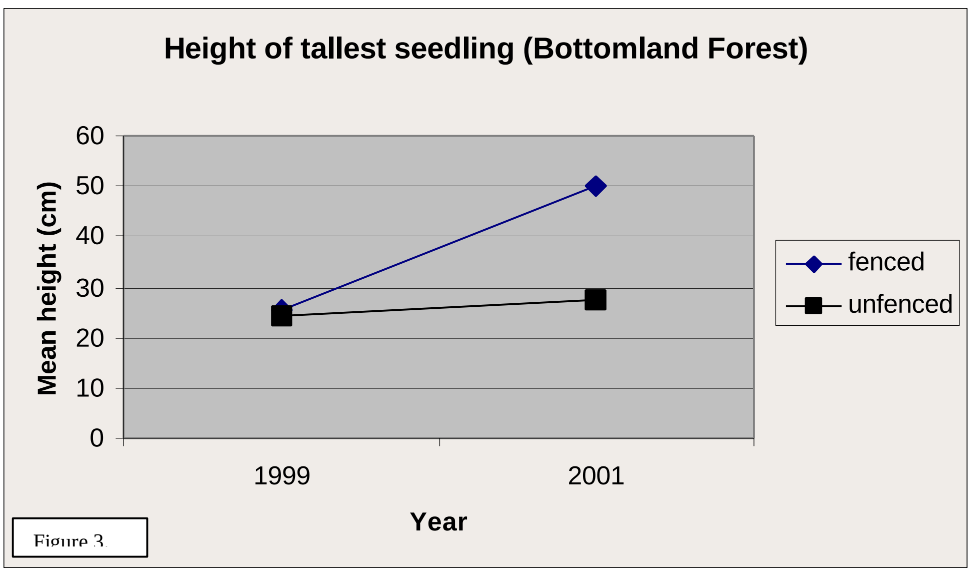
In bottomland forests, the Shannon-Weaver diversity and the native diversity of the groundcover was 18 percent higher on fenced plots. This difference was due to the response on one site, and is not noted on the other two sites in this habitat. On those two sites, the diversity was nearly equal. Other studies have suggested that deer browse affects plant populations less severely when plants are more abundant (see e.g., Augustine et. al. 1998). Bottomland forested sites generally have more groundcover than upland forests, where native diversity differences were significant. It appears that the lush growth of groundcover in the bottomland forests may have allowed bottomland forests to withstand present levels of browse without significant changes in of herbaceous diversity thus far. Alternatively, the diversity may be stable enough, or changing slowly enough that changes may not be apparent over the two year period of treatment.

There were an average of 22,281 total seedlings per hectare on the fenced plots compared to 6,720 on the unfenced plots. Much of this difference is attributable to height class A, where the fenced plots averaged 16,622 seedlings per hectare while the unfenced plots averaged 6,366 In height class B, the fenced plots averaged 5,659 seedlings per hectare, while the unfenced plots averaged only 354. No plots, either fenced or unfenced, contained seedlings in the taller height classes. The smaller number of seedlings on unfenced plots could indicate that numbers of tree seedlings could be reduced over time if browsing continues at present or more elevated levels.

The difference in the ratio of seedlings in height class B to seedlings in height class A between treatments from 1999 to 2001 indicates that the number of seedlings able to progress to taller height classes is severely impacted by deer. In 1999, baseline data on the fenced plots indicated that this ratio was .012 seedlings in height class B for each seedling in height class A. The unfenced plot ratio averaged .111. After two years of exclosure, the fenced plot ratio averaged .340 seedlings in height class B per seedling in height class A. In the unfenced plots, the average was .056. This difference indicates that on the fenced plots, seedlings are beginning to move through the expected progression of growth in the number of seedlings per size class over time. On the unfenced plots, the ratio indicates that only a very small number of seedlings are able to progress to taller height classes, and this number has declined over the last two years, which could indicate that the problem is getting worse.

On the unfenced plots, the tallest seedling averaged 27.3 cm, while on the fenced plots, the tallest seedling averaged 50.0 cm, for a statistically significant average difference of 22.67 cm. In 1999, the height of the tallest seedling was nearly identical on the fenced and unfenced plots, at 25 and 24 centimeters, respectively. After two years of exclosure, the seedlings on the fenced plot were nearly double the height of those on the unfenced plots while those on the unfenced plots remained within three centimeters of the 1999 measurement (see figure 2). The rate of change for the height of the tallest seedling was also significantly different between treatments ($p=.043$, $t=-4.679$)(see figure 3). The significant difference in the height of the tallest seedling, and the rate of change in the height of the tallest seedlings indicate that in bottomland forests, the net growth of tree seedlings and recruitment into taller height classes is suppressed. While many factors including nutrition, light conditions, environmental stressors, and stochastic influences are important to determining the growth rate of plants over time, in CVNP's bottomland forests, white-tailed deer browsing appears to be the limiting factor in seedling growth and recruitment into taller height classes.





There was also a significantly higher number of black cherry seedlings on the fenced plots. On the fenced plots, there were 6,012 seedlings per hectare, compared to 707 per hectare in on the unfenced plots (see figure 4). This difference amounts to a 20 percent higher black cherry composition on the fenced plots. While other studies have shown the opposite trend (see, e.g., Tilghman 1989), it seems that in the bottomland forests of CVNP, deer are suppressing the growth of black cherry seedlings.

This result is the opposite of the upland forests, where deer seem to be altering the relative seedling composition in favor of black cherry. This difference between habitats could be a function of light conditions. In the uplands, the plots had been recently defoliated, whereas the bottomland plots had not. The defoliation in the uplands could have increased the growth rate of the cherry seedlings, which are shade intolerant, to the point that they out-competed other seedlings. In the bottomlands, with less light, and no appreciable defoliation, the cherries would not have this competitive advantage. It is important to note that while the light conditions may be a leading factor in explaining the difference between upland and bottomland results, the difference in seedling composition between fenced and unfenced plots is still attributable to deer impacts, since all defoliated sites in this study had both the fenced and unfenced plots defoliated.

Though not statistically significant, there was a difference between treatments in the number of sugar maple (*Acer saccharum*) seedlings per hectare. On the unfenced plots, no sugar maple seedlings were found, while in the fenced plots, 1768 per hectare were present on average. This suggests that deer may be eliminating the regeneration of sugar maple in the bottomland forests.

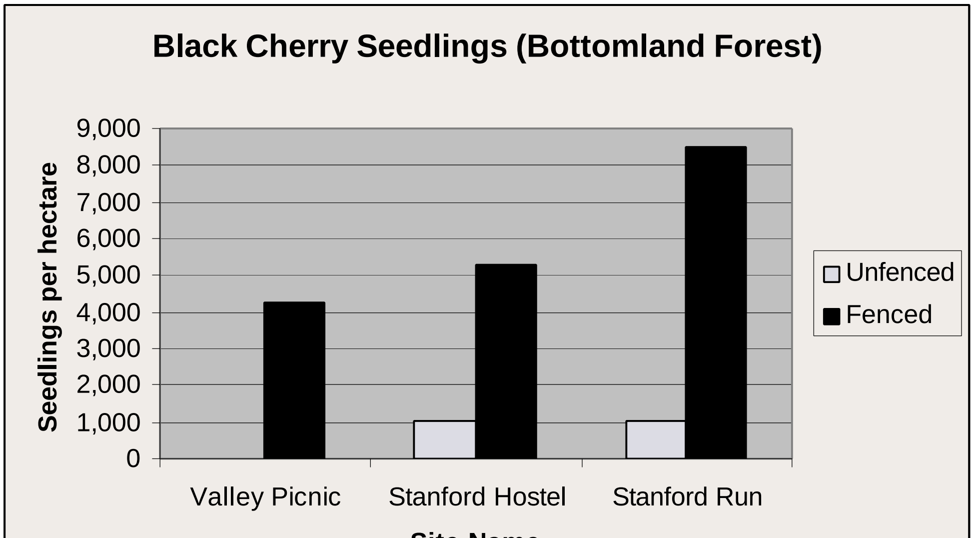


Figure 4

The differences in black cherry and sugar maple regeneration and composition indicate that deer are affecting the composition of the seedling layer in the bottomland forests of CVNP.

Stocking criteria for sustaining high or low deer impacts were not met by fenced or unfenced plots, either in 1999 or 2001. This suggests bottomland forests may not successfully regenerate in the event of overstory mortality (see USDA 1998[c]). Suppression of tree regeneration for long periods of time has been identified as a factor related to alternate stable states in vegetative communities (Stromayer and Warren 1996, Augustine, et. al. 1998).

A deer-induced alternate stable state occurs when a plant community is impacted to such a degree that it crosses a threshold into a lower successional state. Once this threshold is crossed, the original state cannot be restored by merely removing the original stressor (such as deer browsing pressure) from the system (Stromayer and Warren 1996). It is unclear where this threshold lies in CVNP forests. In the Allegheny plateau, an alternate stable state consisting of grasses and ferns developed over many years of high deer densities (Horsely and Marquis 1983). They theorized that when 70 percent of their forested sample plots were stocked with greater than 30% ferns and grasses, an alternate stable state would be likely to occur. More recent views are that grasses may not lead to an alternate stable state, but may merely result in slower regeneration (Stout 2002, pers. com.). If such a state were to occur, a later reduction in deer density would not be likely to succeed in correcting the failure of regeneration. Some further active management would be required to allow recovery of regeneration if an alternate stable state occurred.

While this study has not disclosed conditions indicating that the forests of CVNP are currently in an alternate stable state, such a situation could occur here in the future. Low seedling stocking, and continued decrease in seedling numbers over time, coupled with an increase in the proportion of ferns in unfenced forested plots, could eventually lead to an alternate stable state which would prevent the forests from regenerating even under reduced deer browsing pressure. The quick response to release exhibited by seedlings in the fenced plots indicates that the threshold for entering an alternate stable state has not yet been reached. Thus, at the current time, reduced deer browse intensity would still be sufficient to allow recovery of tree regeneration without further management actions being necessary to accomplish the recovery.

In the bottomland forests, the vertical structure was too variable to draw strong conclusions comparing fenced to unfenced directly, so the rate of change from 1999 to 2001 was compared. The average rate of change in the A level was +33.3 percent on the fenced plots over two years, whereas the average rate of change on the unfenced plots at this height was –16.67 percent. While not statistically significant, this difference in both rate and direction of change indicates that the current deer density, over time, may result in the elimination of foliage near ground level. In the absence of deer, the foliage in this range would be expected to increase over time.

UPLAND FIELDS

In upland fields the groundcover Shannon-Weaver diversity was 19 percent lower on fenced plots and there were more hits on organic litter on the fenced plots. The mean diversity on fenced plots dropped slightly, while that on unfenced plots increased slightly over the two years of exclosure. This may be an indication that deer are browsing the fields heavily enough to cause compensatory growth (see Hobbs 1996), but not heavily enough to begin eliminating species. The consequence of this would be that increased competition from grasses and sedges may limit the growing space for woody species in upland fields that are heavily browsed by deer. This would mean that the natural succession from field to forest may not occur as quickly as it would in the absence of deer browsing pressure.

There were, however, no significant differences in tree regeneration. In general, tree seedling numbers were higher on the unfenced plots. There was a decrease in seedlings on unfenced plots from 1999-2001 and an increase in seedlings on fenced plots during the same time period. However, the differences between treatments were not marked enough to draw reliable conclusions regarding suppression of seedling growth which would be expected based on the facts in the preceding paragraph.

Although a significant difference was noted in the vertical profile of the vegetation in the B height range, this variable displayed significant differences in 1999. For that reason, the difference in foliage at the B level is not attributable to deer. Vertical structure at other heights is nearly identical on fenced and unfenced plots.

BOTTOMLAND FIELDS

No statistically significant differences were found in bottomland fields. However, several non-significant results merit attention. First, groundcover diversity in unfenced plots was 18 percent lower than in fenced plots. This difference carries over in the native diversity, which was also 18 percent lower in the unfenced plots. While the fenced plots exhibited greater diversity prior to exclosure, it appears that the fenced plots increased slightly in diversity while the unfenced plots decreased slightly in diversity over the two years of exclosure. Comparing the species lists (not included in this report) of fenced and unfenced plots results in the observation that there are generally 2 fewer species per plot in the unfenced plots. There is no clear indication that any particular species accounts for this difference across all replicates.

On bottomland field sites the number of seedlings per hectare was slightly higher on the fenced plots compared to the unfenced plots. On fenced plots at two sites which in 1999 had no seedlings present, there were increases in seedlings per hectare, while on the control plots for those sites, no seedlings were counted in either 1999 or 2001. On these same sites, some of the fenced seedlings grew into the B height class on fenced plots.

The average height of the tallest seedling on fenced plots was 128 cm compared to 20 cm on the unfenced plots. This vast difference was not statistically significant due to the variability among replicates (range 45-250 cm), but it is nonetheless representative of conditions on the plots. The difference, along with the fact that two fenced sites exhibited recruitment into the B height class, illustrates the possibility that seedling recruitment into taller height classes may be occurring in fenced plots but not in unfenced plots.

There were no differences between treatments in vertical structure at the tallest height level and the ground level. However, in the intermediate levels, from level B through D, the fenced plots had more vertical structure than the unfenced plots. At these heights, the fenced plots had 33 percent more vertical structure than the unfenced plots in each height range. This suggests that deer limit the height growth of vegetation in the bottomland fields.

SUMMARY OF ANALYSIS

Table one summarizes the conclusions reached based on analysis of the first two years of exclosure data.

Upland forests	
Deer appear to be suppressing increases in native diversity in the groundcover layer*	Deer may facilitate the spread of the non-native invasive plant species *Alliaria officinalis*
Polygonatum and *Smilacina* may decrease in abundance over time due to deer browsing	Deer may be suppressing the recruitment of seedlings into taller height classes
Deer may cause a shift in overstory species composition in the event of overstory mortality and replacement from the seedling bank	Deer may negatively influence the amount of foliage cover
Bottomland forests	
No significant differences in herbaceous diversity between treatments thus far.	Quantity of tree seedlings could be reduced over time if browsing intensity continues at current levels
Deer browsing appears to be the limiting factor in seedling growth and recruitment into taller height classes*	Deer are suppressing the growth of black cherry seedlings, thus impacting the species composition of the seedling bank*

Current deer density may result in the elimination of foliage near ground level over time	Reduced deer browse intensity would still be sufficient to allow recovery of tree regeneration without further management actions being necessary to accomplish the recovery
Upland Fields	
Deer may slow the rate of natural succession from field to forest by increasing groundcover density and diversity	
Bottomland fields	
Deer may decrease vertical structure (foliage)	Deer may suppress the recruitment of seedlings into taller height classes
* indicates that this conclusion was reached based on statistically significant differences between fenced and unfenced plots. All other conclusions are based on interpretation of statistically non-significant differences	

Table 1.

A PROPOSED INDICATOR OF EXCESSIVE DEER IMPACTS

In unperturbed forests, the height of the tallest seedlings is expected to increase, even under heavy shade, while under excessive deer pressure the height of the tallest seedling within reach of deer is expected to decrease or remain stable at a height which deer browse it, as is presently the case in the bottomland forests of CVNP. While many factors including nutrition, light conditions, environmental stressors, and stochastic influences are relevant in determining the height change of seedlings over time, in CVNP's bottomland forests, the significant difference in the height of the tallest seedling, and the rate of change in the height of the tallest seedlings in fenced compared to unfenced plots indicates that white-tailed deer browsing is the limiting factor in seedling growth and recruitment into taller height classes.

In CVNP's upland forests, seedlings protected from deer are more readily able to progress to taller heights than those exposed to current deer densities. While the height of the tallest seedling did not display significant differences, the general status of seedlings supports the conclusion that there is some suppression of the height growth of seedlings in the upland forests, though evidence of impacts was not as significant as in the bottomland forests.

Based on personal observations and qualitative information, the bottomland forests of CVNP appear to be more highly impacted by deer than upland forests (USDA 1998[b]). It stands to reason that if deer impacts on the woody growth in upland forests reach a level similar to the bottomland forests, height growth of seedlings in those areas will also be impeded.

If height growth becomes arrested, it is expected that over time the number of seedlings will begin to decrease as well. The height of the tallest seedling remaining static or decreasing means that either the tallest seedling has not been allowed to grow naturally, or it means that the tallest seedling has been killed and a previously shorter seedling became the tallest. In either case, over time this would lead to decreasing seedling numbers, particularly in areas with greater shade (Canham et. al. 1994). Based on this reasoning, it follows that areas in which the height of the tallest seedling is decreasing over time will also exhibit decreases in the number of seedlings over time. Before such a decrease is apparent, it is probable that the number of seedlings in the shortest height class will greatly exceed the number of seedlings in the next taller height class, indicating the inability of the seedlings to progress in height growth. The 2001 LTEM data, as well as future exclosure data, should be examined for consistency with this hypothesis. If this holds true, then the change in height of the tallest seedling may also be a sensitive enough indicator to alert resource managers to possible decreases in seedling abundance before such decreases become significant. Other tree regeneration related variables expected to be related to the change in height of the tallest seedling are stocking, weighted seedlings, and seedlings in each height class. Each of these values is expected to be lower at sites where the height of the tallest seedling has decreased, since they are all closely related variables which have been shown in other studies to be impacted by deer.

Available scientific information (deCalesta 1998, Tilghman 1989) suggests that deer impacts may become noticeable on herbaceous vegetation before they become apparent on seedling regeneration. While the park's *Trillium* monitoring has disclosed negative impacts to reproduction and height growth of *Trillium grandiflorum*, a sensitive indicator of deer impacts to herbaceous vegetation (Plona 2002), it is not clear that at present deer densities the groundcover Shannon and native *diversity* is being unacceptably impacted. In bottomlands, the native diversity was nearly static in both fenced and unfenced plots during the time examined in this report. In the uplands, the rate of native diversity increase is apparently being suppressed in the unfenced plots. Although the native diversity is rising on the unfenced plots as well as the fenced plots, it is increasing at a significantly greater rate in fenced plots. Current diversity trends may be altered by widespread gypsy moth defoliation in the park, which may have provided a significant temporary source of alternative forage for deer, effectively lessening the browse pressure in broad areas of the park. This factor prevents drawing strong conclusions about the groundcover diversity park wide based on the samples examined in the exclosure study.

Increases in diversity over time are expected (McLachlan & Bazely 2001) since many of CVNP's forests are young and have not fully developed the understory layer typical of the area's older forests. The "natural" rate of increase in diversity is unknown. It is assumed that so long as native diversity is increasing measurably that some level of deer impacts on plant diversity are acceptable. This assumption must be considered in light of the fact that as a forest matures, certain plants that are not adapted for the low light conditions and other attributes of an older forest are expected to become less significant components of the plant community. Thus, after increasing over time, groundcover diversity is expected to remain steady or decrease slightly over time.

Because the rate of change in the height of the tallest seedling in the bottomland forests is significantly different between fenced and unfenced plots, while groundcover native diversity displays no differences between fenced and unfenced plots in the bottomlands, and currently appears to be increasing even under present deer impacts in the uplands, it seems that the direction of change in the height of the tallest seedling may indicate adverse deer impacts sensitively enough to be able to alert managers to problems before irreversible impacts occur to groundcover diversity. Furthermore, while the exclosure data suggests that deer are currently reducing seedling numbers in bottomland forests, seedlings have not been eliminated. Thus, it may be that impacts to seedling height growth appear in CVNP's forests before critical reductions in seedling numbers occur.

The direction of change in height of the tallest seedling is a useful indicator of excessive deer browse for several reasons. Height increase itself is an ecosystem component of interest, since seedlings must grow in height to replace canopy trees. In CVNP's forests, change in seedling height has a known, direct relationship to deer, and apparently exhibits signs of excessive deer impacts before seedling numbers and possibly groundcover diversity do, making it useful as a warning about future deer impacts to those variables. The change in height is easily measured, both accurately and precisely. Seedlings are well distributed across the natural areas of the park, both in forests and fields, making them widespread enough to be examined on a broad spatial scale.

Limitations in the use of this indicator are potential auto-correlation between this and other variables that are not deer-related, and complex inter-correlation with other factors which influence the height growth of seedlings. So long as analysis of data properly accounts for potential confounding factors, these limitations do not greatly impact the practical application of this indicator.

It is recommended that the direction of change in height of the tallest seedling be used in conjunction with long term ecological monitoring data by classifying LTEM sites which exhibit a positive change in the height of the tallest seedling over the two most recent observations as lower impact sites, while those exhibiting no change, or negative changes would be designated high impact sites. In cases where the height of the tallest seedling has decreased due to identified factors other than deer, such as growth of the former tallest seedling beyond the seedling stage, natural thinning, or pathogens, as noted on LTEM data sheets, that LTEM site should be considered a lower impact area. This may result in some areas with high deer impacts being mis-classified as lower impact areas in the absence of an alternative indicator. However, if seedling height has been observably impeded by a factor other than deer browsing, at this time no other reliable indicator has been identified to allow us to classify that site as a high or lower deer impact area. By default such sites would be considered lower impact areas until such time as an identified objective indicator suggests otherwise.

The data may also be used to derive GIS based deer impact maps to identify regions of the park being the most severely impacted by deer, as well as less impacted areas. It is likely that there will be significant differences in at least some variables in the LTEM data set between high and lower deer impact areas as identified by the change in height of the tallest seedling. Native and Shannon diversity indices will probably be higher in lower impact areas, as may seedlings per hectare in each height class other than the shortest class, total seedlings per hectare, weighted seedlings per hectare, and the stocking variables which are based on height weighted seedling counts. By examining differences between LTEM sites designated high or lower impact areas, further impacts of deer may be identified.

These differences, if apparent, will support the concept of using this indicator because these variables are the very factors which the exclosure data and other studies have identified as being related to deer impacts. If significant differences between high and lower deer impact areas are found, the differences should be examined for correlation with other factors which may influence the variables before concluding that they are caused by deer impacts. In the absence of such apparent confounding factors, differences between high and lower deer impact areas can be attributed to deer impacts. In this way, it is possible to identify high impact areas in time to provide resource managers necessary information to make management decisions before park vegetation sustains long term adverse impacts or becomes impaired.

Using the indicator identified herein at LTEM sampling sites will allow resource managers to pinpoint areas with high deer impacts to seedlings and overall groundcover diversity without regard to confounding factors that may render it difficult to use fecal pellet counts as a predictor of deer impacts.

CVNP currently uses fecal pellet counts along 50-meter transects as a means of estimating deer distribution across the park. These counts are taken in spring and are used to create deer distribution maps. In the LTEM analysis performed in 1998, the pellet counts along transects located at vegetation monitoring plots were used as surrogates for deer density, under the assumption that areas with higher pellet counts would be areas of higher deer density, which in turn might correspond with higher deer impact. This framework does not take into account the capacity for different areas to sustain different densities of deer due to factors such as availability, type and amount of alternative forage, stage of stand development, or other factors which may influence deer impacts. The 1998-1999 LTEM report was able to relate fecal pellet counts in bottomland forests with lower seedling height and weighted seedling counts for 1998. However, no significant relationships were found in the 1999 data for those areas, nor were any relationships apparent in any of the other strata in 1998. No other variables were significantly related to deer pellet counts in 1998 or 1999 data. In recent attempts at reanalysis of the 1998 LTEM data, other potential indicators of high deer impacts, such as percent browse, total browse hits, and using pellet counts from earlier years to isolate a lag effect in deer impacts versus deer population fluctuations have all proven inconclusive. While in the past it was reasonable to assume the possibility that no correlation existed because the deer impacts were not significant enough to become apparent, this assumption is no longer valid. In light of the impacts identified in this exclosure study, it is reasonable to conclude that late winter/early spring deer pellet counts alone are not a reliable indicator of deer impacts.

The lack of correlation between apparent deer impacts and pellet counts may be related to the large amounts of suburban and agricultural forage available to deer. The availability of alternative forage may tend to limit deer impacts to herbaceous vegetation, since the availability of agricultural and landscaping forage roughly parallels the availability of native herbaceous vegetation. In winter, when the native herbaceous vegetation has senesced and the agricultural crops have been harvested, deer would be expected to impact the woody growth in the park more severely than the herbaceous growth. This would explain why groundcover diversity does not show the pronounced impacts one would expect given the state of tree seedling regeneration. Using change in height of the tallest seedling as an indicator removes the "noise" imposed by these unknown factors and identifies high impact areas without regard for deer density, availability of alternative forage, feeding preferences, differences between sites' resilience to browsing, habitat quality, or other influences.

Preferred species of plants are known to decrease in height, vigor, reproductive output, and density under increasing browse pressure, while non-preferred plants tend to increase. Current exclosure data does not indicate that species loss and replacement or adverse height or reproductive impacts due to cumulative effects of browsing over time may be predicted using change in height of the tallest seedling, other than to speculate that these impacts are more likely to occur in areas identified as high impact areas using this indicator. Negative impacts of this nature should still be monitored through other indicators such as *Trillium*, which is known to be positively correlated with reproductive output by perennial herbaceous plants and negatively correlated with the percent of the herbaceous understory that was browsed (Anderson 1994), and which has been monitored for deer impacts since the mid-1990's and continues to indicate excessive deer impacts to herbaceous vegetation.

As more information becomes available on the influences of environmental factors on the intensity of deer impacts, fecal pellet counts or other variables may possibly become more useful in identifying and predicting deer impacts. Until better methods and indicators are identified, the direction of height change of the tallest seedling is the best available indicator of the spatial patterns and quality of deer impacts on the vegetation of CVNP. If park managers use this indicator to identify areas of excessive deer impacts, and couple that knowledge with appropriate management actions to alleviate the adverse impacts associated with the indicator, the exclosure data suggest that expected natural growth trends of woody seedlings, an increase in seedling numbers, and possibly an elevated rate of increase in groundcover native diversity are likely to result.

CONCLUSION AND RECOMMENDATIONS

The conclusions summarized in table 1 above indicate that deer are impacting the forest and field vegetation of CVNP. In the upland forests, deer decrease groundcover diversity, and may be inhibiting recruitment of seedlings into taller height classes. In these areas, deer may also contribute to the spread of *Alliaria officinalis*, as well as potentially impacting populations of members of the lily family, such as *Smilacina racemosa* and *Polygonatum pubescens*. Deer also appear to reduce the amount of vertical structure, and hence foliage cover in upland forests.

Adverse effects of deer on seedling regeneration appear to be most pronounced in bottomland forests, which other reports and the literature have identified as areas likely to be heavily used by deer (USDA 1998[b], Zwank 1979). In bottomland forests, seedling height growth is inhibited, the height of the tallest seedling and recruitment to taller height classes is limited by deer, and the composition of the seedling population is being altered by deer. Seedling numbers may also be reduced over time in bottomland forests. However, it appears that, in light of the quick response to protection from browsing observed in this study, the bottomland forests would be able to recover well from these impacts, so long as the browsing intensity is reduced or mitigated in the near future. Otherwise, an alternate stable state could occur which would compromise the ability of the forests to recover. While there is currently no evidence from this study which would indicate that such a state is imminent, the threshold for an alternative stable state is not known in CVNP. The factors leading to such a state, as outlined in the scientific literature cited, should be prevented in order to decrease the risk of crossing this unknown threshold which could lead to an impairment of park natural resources.

In upland fields, deer are apparently contributing to increased groundcover diversity and density, which could be interpreted as a positive effect of deer browsing. However, this situation could slow the process of succession from open field to old field to shrubby field to young forest significantly by giving field vegetation enough of a competitive advantage that woody species are prevented from establishing themselves in the upland fields of the park. In bottomland fields, deer may be suppressing seedling recruitment and growth, as well as decreasing the vertical structure.

Present deer impacts to the forests suggest that with prolonged deer browsing pressure at current levels, CVNP will have less groundcover diversity in upland forests, experience unacceptably low levels of advance seedling regeneration, and losses in vertical foliage profile. The upland forests may undergo a shift in the canopy species composition, as will bottomland forests, if they are able to regenerate at all. It is likely that as browsing at current levels continues, evidence of deer impacts will become clearer in all habitats. Over time continued browsing at current levels is expected to lead to elimination of preferred species, a failure of forest regeneration in some areas, and a perpetuation of field and edge habitats at an arrested stage of succession which would keep the habitat ideal for deer, but would not allow the process of natural succession to proceed.

Deer are having adverse impacts on the forest vegetation of CVNP, and may be impacting fields as well. Means of preventing and ameliorating this damage should be explored. The deer impacts identified in this report should be integrated into the analysis of the LTEM data collected in 2001 to identify impacted areas of the park, and possibly identify further correlation in the vegetative conditions in those areas. Specifically, the change in height of the tallest tree seedling over time should be used as an indicator of high deer impacts as explained above. The relationship between wildlife and the spread of non-native invasive plants such as *Alliaria* should be researched. Monitoring of Deer Exclosures should continue on a three to five year basis, with the next remeasurement occurring at the earliest during the spring and summer of 2004.

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Appendix A

(**Bold** indicates variables with statistically significant differences)

Upland Forested Sites 2001

Exclosure Name	Coonrad Woods		Armington		Optimist Club		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Seedlings per hectare	80,697	133,686	43,501	138,991	11,671	4,244	45,290	92,307	1.575	0.256	2
Weighted Seedlings/Ha	619,624	421,217	154,906	199,468	12,732	5,305	262,421	208,663	-0.728	0.542	2
Seedlings/Ha 5-30	33,952	91,246	35,013	135,808	10,610	3,183	26,525	76,746	1.597	0.251	2
Seedlings/Ha 30-1	22,281	29,708	4,244	1,061	1,061	1,061	9,195	10,610	0.450	0.697	2
Seedlings/Ha1-1.5	12,732	7,427	1,061	0	0	0	4,598	2,476	-1.309	0.321	2
Seedlings/Ha>1.5	11,671	5,305	3,183	2,122	0	0	4,951	2,476	-1.257	0.336	2
Prunus Serotina	29,708	45,623	0	25,464	0	0	9,903	23,696	1.857	0.204	2
Fraxinus Americana	9,549	2,122	3,183	1,061	1,061	2,122	4,598	1,768	-1.143	0.371	2
Acer Rubrum	18,037	40,318	16,976	81,697	1,061	0	12,024	40,671	1.488	0.275	2
Acer Saccharum	0	0	3,183	4,244	0	0	1,061	1,415	1.000	0.423	2
%Plots with ≥10 seedlings	100	100	100	100	0	0	67	67	0.000	1	2
%Plots with ≥30 seedlings	100	100	66	100	0	0	55	67	1.522	0.268	2
Height of Tallest	250	300	400	270	32	95	227	222	-0.091	0.936	2
Browse Hits	0	11	0	0	0	3	0	4.67	1.421	0.291	2
Total Plant Hits	96	40	82	47	72	99	83	62	-0.856	0.482	2
Organic Litter Hits	41	93	67	85	68	49	59	76	0.829	0.494	2
Shannon Diversity	0.95446	0.59132	0.96377	0.73774	1.03487	1.02971	0.98437	0.78626	-1.900	0.198	2
Native Diversity	**0.91746**	**0.59132**	**0.96377**	**0.73774**	**0.97818**	**0.87208**	**0.95314**	**0.73371**	**-3.450**	**0.075**	**2**
Veg. Profile 1/2m	6	5	5	0	3	4	4.67	3.00	-0.945	0.444	2
Veg. Profile 1m	5	3	2	0	0	1	2.33	1.33	-1.000	0.423	2
Veg. Profile 1 1/2m	5	3	0	0	0	0	1.67	1.00	-1.000	0.423	2
Veg. Profile 2 m	5	4	1	1	0	0	2.00	1.67	-1.000	0.423	2
Veg. Profile > 2 m	4	1	5	2	1	0	3.33	1.00	-3.500	0.073	2
Percent Canopy	84	82	93	93	92	90	90	88	-2.000	0.184	2

Bottomland Forested Sites 2001

Exclosure Name	Valley Picnic		Stanford Hostel		Stanford Run		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Seedlings per hectare	9,549	6,366	29,708	9,549	27,586	4,244	22,281	6,720	-2.487	0.131	2
Weighted Seedlings/Ha	10,610	7,427	33,952	9,549	41,379	4,244	28,647	7,073	-2.179	0.161	2
Seedlings/Ha 5-30	8,488	5,305	25,464	9,549	15,915	4,244	16,622	6,366	-2.740	0.111	2
Seedlings/Ha 30-1	1,061	1,061	4,244	0	11,671	0	5,659	354	-1.555	0.260	2
Seedlings/Ha1-1.5	0	0	0	0	0	0	0	0	0.000	1.000	2
Seedlings/Ha>1.5	0	0	0	0	0	0	0	0	0.000	1.000	2
Prunus Serotina	**4,244**	**0**	**5,305**	**1,061**	**8,488**	**1,061**	**6,012**	**707**	**-5.000**	**0.038**	**2**
Fraxinus Americana	3,183	6,366	2,122	2,122	1,061	1,061	2,122	3,183	1.000	0.423	2
Acer Rubrum	0	0	0	0	0	0	0	0	0.000	1.000	2
Acer Saccharum	0	0	0	0	5,305	0	1,768	0	-1.000	0.423	2
%Plots with ≥10 seedlings	0	0	33	0	66	0	33	0	-1.732	0.225	2
%Plots with ≥30 seedlings	0	0	0	0	0	0	0	0	0.000	1.000	2
Height of Tallest	**60**	**45**	**40**	**25**	**50**	**12**	**50**	**27**	**-2.957**	**0.098**	**2**
Browse Hits	0	5	0	0	0	3	0	2.67	1.350	0.208	2
Total Plant Hits	114	129	130	125	118	61	121	105	-0.730	0.541	2
Organic Litter Hits	31	17	13	8	25	54	23	26	0.255	0.823	2
Shannon Diversity	1.18654	1.09295	0.87585	0.35220	0.68130	0.79880	0.91456	0.74798	-0.883	0.470	2
Native Diversity	1.14707	1.06622	0.78617	0.33464	0.68130	0.79880	0.87151	0.73322	-0.829	0.494	2
Veg. Profile 1/2m	6.00	6.00	6.00	6.00	5.00	0.00	5.67	4.00	-1.000	0.423	2
Veg. Profile 1m	1.00	3.00	1.00	0.00	0.00	0.00	0.67	1.00	0.378	0.742	2
Veg. Profile 1 1/2m	1.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	-1.000	0.423	2
Veg. Profile 2 m	0.00	1.00	1.00	1.00	0.00	0.00	0.33	0.67	1.000	0.423	2
Veg. Profile > 2 m	1.00	3.00	0.00	3.00	1.00	0.00	0.67	2.00	1.109	0.383	2
Percent Canopy	89.00	90.00	84.00	90.00	88.00	93.00	87.00	91.00	2.619	0.120	2

Appendix A

(**Bold** indicates variables with statistically significant differences)

Upland Field Sites 2001

Exclosure Name	Terra Vista		Wheatley		Borrow Pit		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Total Seedlings/ha	3,183	0	10,610	27,586	1,061	5,305	4951	10964	1.021	0.414	2
Weighted Seedlings/ha	6,366	0	18,037	43,501	2,122	8,488	8842	17330	0.918	0.456	2
Seedlings/ha 5-30cm tall	0	0	3,183	11,671	0	2,122	1061	4598	1.387	0.300	2
Seedlings/ha 30cm-1m tall	2,122	0	5,305	12,732	1,061	2,122	2829	4951	0.756	0.529	2
Seedlings/ha 1-1.5m tall	1,061	0	1,061	1,061	0	1,061	707	707	0.000	1.000	2
Seedlings/ha > = 1.5m tall	0	0	1,061	2,122	0	0	354	707	1.000	0.423	2
Black Cherry Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
White Ash Seedlings/ha	0	0	5,305	15,915	1,061	5,305	2122	7073	1.606	0.250	2
Red Maple Seedlings/ha	0	0	0	1,061	0	0	0	354	1.000	0.423	2
Sugar Maple Seedlings/ha	0	0	0	2,122	0	0	0	707	1.000	0.423	2
%Plots with >10 seedlings	33	0	66	100	0	33	33	44	0.511	0.660	2
%Plots with >30 seedlings	0	0	33	66	0	0	11	22	1.000	0.423	2
Height of Tallest Seedling	125	0	325	325	31	145	160	157	-0.053	0.962	2
Browse Hits	0	3	0	10	0	4	0.00	5.67	2.592	0.122	2
Total Plant Hits	150	149	149	148	145	150	148	149	0.500	0.667	2
Organic Litter Hits	0	0	2	0	0	0	0.67	0.00	-1.000	0.423	2
Shannon Diversity	0.60322	0.93365	0.86872	0.92140	0.55364	0.69949	0.6752	0.8515	2.160	0.163	2
Native Diversity	0.52549	0.86597	0.82518	0.89082	0.55364	0.69949	0.6348	0.8188	2.255	0.153	2
Veg. Profile 1/2m	6.00	6.00	6.00	6.00	6.00	5.00	6.00	5.67	-1.000	0.423	2
Veg. Profile 1m	**3.00**	**0.00**	**4.00**	**3.00**	**6.00**	**2.00**	**4.33**	**1.67**	**-3.024**	**0.094**	**2**
Veg. Profile 1 1/2m	0.00	0.00	1.00	1.00	0.00	0.00	0.33	0.33	0.000	1.000	2
Veg. Profile 2 m	0.00	0.00	1.00	1.00	0.00	0.00	0.33	0.33	0.000	1.000	2
Veg. Profile > 2 m	0.00	0.00	2.00	2.00	0.00	0.00	0.67	0.67	0.000	1.000	2

Bottomland Field Sites 2001

Exclosure Name	Coonrad Field		Trailer Park		Ira Trailhead		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Total Seedlings/ha	3,183	8,488	2,122	0	5,305	0	3,537	2,829	-0.225	0.843	2
Weighted Seedlings/ha	6,366	13,793	3,183	0	8,488	0	6,012	4,598	-0.302	0.791	2
Seedlings/ha 5-30cm tall	0	3,183	1,061	0	2,122	0	1,061	1,061	0.000	1.000	2
Seedlings/ha 30cm-1m tall	1,061	5,305	1,061	0	3,183	0	1,768	1,768	0.000	1.000	2
Seedlings/ha 1-1.5m tall	0	0	0	0	0	0	0	0	0.000	1.000	2
Seedlings/ha > = 1.5m tall	2,122	0	0	0	0	0	707	0	-1.000	0.423	2
Black Cherry Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
White Ash Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
Red Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
Sugar Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
%Plots with >10 seedlings	33	33	0	0	0	0	11	11	0.000	1.000	2
%Plots with >30 seedlings	33	0	0	0	0	0	11	0	-1.000	0.423	2
Height of Tallest Seedling	250	60	90	0	45	0	128	20	-2.528	0.127	2
Browse Hits	0	51	0	0	0	0	0	17	1.000	0.423	2
Total Plant Hits	104	150	135	144	150	150	130	148	1.303	0.323	2
Organic Litter Hits	31	0	14	5	0	0	15	2	-1.448	0.285	2
Shannon Diversity	1.03362	0.70111	0.96465	0.86474	0.96194	0.82782	0.98674	0.79789	-2.605	0.121	2
Native Diversity	0.96309	0.64080	0.83906	0.78526	0.96194	0.82782	0.92136	0.75129	-2.138	0.166	2
Veg. Profile 1/2m	6	6	6	6	6	6	6.00	6.00	0.000	1.000	2
Veg. Profile 1m	6	0	1	3	2	0	3.00	1.00	-0.866	0.478	2
Veg. Profile 1 1/2m	6	0	1	1	1	0	2.67	0.33	-1.257	0.336	2
Veg. Profile 2 m	4	0	1	0	0	0	1.67	0.00	-1.387	0.300	2
Veg. Profile > 2 m	1	0	0	1	0	0	0.33	0.33	0.000	1.000	2

Appendix A

(**Bold** indicates variables with statistically significant differences)

Upland Forested Sites 1999

Exclosure Name	Coonrad Woods		Armington		Optimist Club		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			2
Total Seedlings/ha	80636	71087	9549	9549	14854	10610	35013	30415.33	-1.164	0.238	2
Weighted Seedlings/ha	128381	170821	72148	71087	14854	10610	71794.33	84172.67	0.822	0.497	2
Seedlings/ha 5-30cm tall	62599	60477	6366	7427	14854	10610	27939.67	26171.33	-1.147	0.370	2
Seedlings/ha 30cm-1m tall	16976	7427	1061	0	0	0	6012.333	2475.667	-1.170	0.362	2
Seedlings/ha 1-1.5m tall	0	0	0	0	0	0	0	0	0.000	1.000	2
Seedlings/ha > = 1.5m tall	1061	3183	2122	2122	0	0	1061	1768.333	1.000	0.423	2
Black Cherry Seedlings/ha	32891	46684	0	3183	1061	3183	11317.33	17683.33	1.708	0.230	2
White Ash Seedlings/ha	16976	4244	3183	1061	1061	1061	7073.333	2122	-1.257	0.336	2
Red Maple Seedlings/ha	26525	5305	2122	4244	2122	0	10256.33	3183	-0.985	0.428	2
Sugar Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
%Plots with $\geq$10 seedlings	100	100	33	66	0	0	44.33333	55.33333	1.000	0.423	2
%Plots with $\geq$30 seedlings	33	66	33	66	0	0	22	44	2.000	0.184	2
Height of Tallest Seedling	180	200	230	207	24	200	144.6667	202.3333	0.954	0.441	2
Browse Hits	0	0	0	0	0	0	0	0	0.000	1.000	2
Total Plant Hits	25	30	44	29	102	120	57	59.66667	0.278	0.807	2
Organic Litter Hits	116	107	104	108	52	29	90.66667	81.33333	-1.197	0.354	2
Shannon Diversity	**0.67259**	**0.4714764**	**0.5958**	**0.375512**	**0.6773**	**0.577633**	**0.648564**	**0.474874**	**-4.640**	**0.043**	**2**
Native Diversity	0.59948	0.4714764	0.5958	0.375512	0.5072	0.561381	0.567515	0.469456	-1.216	0.348	2
Veg. Profile 1/2m	4	2	0	0	2	5	2	2.333333	0.229	0.840	2
Veg. Profile 1m	1	1	0	0	0	0	0.333333	0.333333	0.000	1.000	2
Veg. Profile 1 1/2m	1	2	0	1	0	0	0.333333	1	2.000	0.184	2
Veg. Profile 2 m	2	0	0	0	0	0	0.666667	0	-1.000	0.423	2
Veg. Profile > 2 m	1	0	0	0	1	0	0.666667	0	-2.000	0.184	2
Percent Canopy	33	34	28	31	89	89	50	51.33333	1.512	0.270	2

Bottomand Forested Sites 1999

Exclosure Name	Valley Picnic		Stanford Hostel		Stanford Run		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			2
Total Seedlings/ha	60477	41379	15915	16976	11671	5305	29354.33	21220	-1.382	0.301	2
Weighted Seedlings/ha	61538	47745	15915	16976	11671	5305	29708	23342	-1.485	0.276	2
Seedlings/ha 5-30cm tall	59416	35013	15915	16976	11671	5305	29000.67	19098	-1.310	0.321	2
Seedlings/ha 30cm-1m tall	1061	6366	0	0	0	0	353.6667	2122	1.000	0.423	2
Seedlings/ha 1-1.5m tall	0	0	0	0	0	0	0	0	0.000	1.000	2
Seedlings/ha > = 1.5m tall	0	0	0	0	0	0	0	0	0.000	1.000	2
Black Cherry Seedlings/ha	54111	31830	1061	1061	4244	0	19805.33	10963.67	-1.294	0.325	2
White Ash Seedlings/ha	1061	7427	3183	3183	1061	1061	1768.333	3890.333	1.000	0.423	2
Red Maple Seedlings/ha	0	1061	6366	7427	3183	1061	3183	3183	0.000	1.000	2
Sugar Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
%Plots with $\geq$10 seedlings	100	66	0	0	0	0	33.33333	22	-1.000	0.423	2
%Plots with $\geq$30 seedlings	0	0	0	0	0	0	0	0	0.000	1.000	2
Height of Tallest Seedling	40	46	15	14	21	13	25.33333	24.33333	-0.247	0.828	2
Browse Hits	0	0	0	0	0	3	0	1	1.000	0.423	2
Total Plant Hits	85	117	123	136	78	28	95.33333	93.66667	-0.067	0.952	2
Organic Litter Hits	57	27	20	12	64	105	47	48	0.048	0.966	2
Shannon Diversity	1.15717	1.1040885	0.4761	0.097906	0.6509	0.634927	0.7614	0.612307	-1.296	0.324	2
Native Diversity	1.13548	1.0688515	0.2585	0.097906	0.6509	0.634927	0.681644	0.600561	-1.913	0.196	2
Veg. Profile 1/2m	4	6	6	6	1	3	3.666667	5	2.000	0.184	2
Veg. Profile 1m	1	3	0	0	0	0	0.333333	1	1.000	0.423	2
Veg. Profile 1 1/2m	0	0	0	0	0	0	0	0	0.000	1.000	2
Veg. Profile 2 m	0	1	0	0	0	0	0	0.333333	1.000	0.423	2
Veg. Profile > 2 m	1	2	0	1	0	0	0.333333	1	2.000	0.184	2
Percent Canopy	90	81	84	85	89	64	87.66667	76.66667	-1.453	0.283	2

Appendix A

(**Bold** indicates variables with statistically significant differences)

Upland field Sites 1999

Exclosure Name	Terra Vista		Wheatley		Borrow Pit		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Total Seedlings/ha	4244	0	5305	26525	1061	6366	3536.667	10963.67	1.000	0.423	2
Weighted Seedlings/ha	6366	0	66843	145357	1061	40318	24756.67	61891.67	1.514	0.269	2
Seedlings/ha 5-30cm tall	2122	0	1061	10610	1061	2122	1414.667	4244	0.812	0.502	2
Seedlings/ha 30cm-1m tall	2122	0	1061	11671	0	3183	1061	4951.333	1.054	0.403	2
Seedlings/ha 1-1.5m tall	0	0	2122	1061	0	0	707.3333	353.6667	-1.000	0.423	2
Seedlings/ha > = 1.5m tall	0	0	1061	3183	0	1061	353.6667	1414.667	1.732	0.225	2
Black Cherry Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
White Ash Seedlings/ha	0	0	2122	22281	1061	6366	1061	9549	1.407	0.295	2
Red Maple Seedlings/ha	0	0	0	2122	0	0	0	707.3333	1.000	0.423	2
Sugar Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
%Plots with $\geq$10 seedlings	0	0	100	100	0	33	33.33333	44.33333	1.000	0.423	2
%Plots with $\geq$30 seedlings	0	0	33	66	0	33	11	33	2.000	0.184	2
Height of Tallest Seedling	58	0	350	230	21	161	143	130.3333	-0.162	0.886	2
Browse Hits	0	5	0	4	0	0	0	3	1.964	0.188	2
Total Plant Hits	148	146	141	134	145	149	144.6667	143	-0.524	0.652	2
Organic Litter Hits	2	4	9	10	5	0	5.333333	4.666667	-0.305	0.789	2
Shannon Diversity	0.92523	1.003686	0.906	0.794797	0.4722	0.717165	0.767821	0.838549	0.687	0.563	2
Native Diversity	0.8389	0.853811	0.874	0.768079	0.4722	0.704336	0.728376	0.775409	0.476	0.681	2
Veg. Profile 1/2m	6	6	6	6	6	6	6	6	0.000	1.000	2
Veg. Profile 1m	**2**	**0**	**4**	**1**	**2**	**1**	**2.666667**	**0.666667**	**-3.464**	**0.074**	**2**
Veg. Profile 1 1/2m	0	0	0	1	0	0	0	0.333333	1.000	0.423	2
Veg. Profile 2 m	0	0	2	2	0	0	0.666667	0.666667	0.000	1.000	2
Veg. Profile > 2 m	0	0	3	2	0	0	1	0.666667	-1.000	0.423	2

Bottomland Field Sites 1999

Exclosure Name	Coonrad Field		Trailer Park		Ira Trailhead		Means		t	p	df
Fenced/Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced	Fenced	Unfenced			
Total Seedlings/ha	3183	2122	0	0	0	0	1061	707.3333	-1.000	0.423	2
Weighted Seedlings/ha	20159	2122	0	0	0	0	6719.667	707.3333	-1.000	0.423	2
Seedlings/ha 5-30cm tall	0	2122	0	0	0	0	0	707.3333	1.000	0.423	2
Seedlings/ha 30cm-1m tall	2122	0	0	0	0	0	707.3333	0	-1.000	0.423	2
Seedlings/ha 1-1.5m tall	1061	0	0	0	0	0	353.6667	0	-1.000	0.423	2
Seedlings/ha > = 1.5m tall	0	0	0	0	0	0	0	0	0.000	1.000	2
Black Cherry Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
White Ash Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
Red Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
Sugar Maple Seedlings/ha	0	0	0	0	0	0	0	0	0.000	1.000	2
%Plots with $\geq$10 seedlings	33	0	0	0	0	0	11	0	-1.000	0.423	2
%Plots with $\geq$30 seedlings	0	0	0	0	0	0	0	0	0.000	1.000	2
Height of Tallest Seedling	110	28	0	0	0	0	36.66667	9.333333	-1.000	0.423	2
Browse Hits	0	26	0	2	0	1	0	9.666667	1.183	0.358	2
Total Plant Hits	150	150	130	142	147	147	142.3333	146.3333	1.000	0.423	2
Organic Litter Hits	0	0	14	2	1	2	5	1.333333	-0.878	0.473	2
Shannon Diversity	**0.85886**	**0.777707**	**0.9647**	**0.899931**	**0.79**	**0.756687**	**0.871208**	**0.811442**	**-4.262**	**0.051**	**2**
Native Diversity	0.71521	0.681997	0.507	0.250798	0.79	0.706308	0.67076	0.546368	-1.843	0.207	2
Veg. Profile 1/2m	6	6	6	6	6	6	6	6	0.000	1.000	2
Veg. Profile 1m	4	1	2	1	2	3	2.666667	1.666667	-0.866	0.478	2
Veg. Profile 1 1/2m	2	0	0	1	0	1	0.666667	0.666667	0.000	1.000	2
Veg. Profile 2 m	0	0	0	1	1	0	0.333333	0.333333	0.000	1.000	2
Veg. Profile > 2 m	0	0	0	0	2	0	0.666667	0	-1.000	0.423	2